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CALIBRATION OF ANGLE-OF-ATTACK AND DYNAMIC PRESSURE SENSORS ON THE MODULAR-GUIDED GLIDE BOMB AT TRANSONIC MACH NUMBERS

D. A. MacLanahan, Jr.

ARO, Inc.

September 1972

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FOREWORD

The work report herein was done at the request of the Air Force Armament Laboratory (AFATL/DLZ-1/Dr. Zipfel) for Celesco Industries under Program Element 63741F.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-73-C-0004. The test was conducted from June 23 to June 24, 1972, under ARO Project No. PA011 (PB0298). The manuscript was submitted for publication on August 4, 1972.

This technical report has been reviewed and is approved.

L. R. KISSLING
Lt Colonel, USAF
Chief Air Force Test Director, PWT
Directorate of Test

A. L. COAPMAN
Colonel, USAF
Director of Test

ABSTRACT

A wind tunnel test was conducted at Mach numbers from 0.60 to 0.90 in the Propulsion Wind Tunnel Transonic (16T) to provide a calibration of angle-of-attack and dynamic pressure sensors mounted on a full-scale Modular-Guided Glide Bomb (MGGB) with the glide bomb tail section removed and the wing span shortened. The data indicate that in addition to the data supplied by the manufacturer of the angle-of-attack vanes, calibration data are necessary to properly define the attitude of the vehicle. The dynamic pressure sensor readings must be reduced by approximately 25 percent to yield accurate free-stream data at Mach numbers from 0.60 to 0.80.

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APPENDIX
ILLUSTRATIONS

NOMENCLATURE

ALF1	MGGB vane angle of attack, positive nose up, deg
ALF2	Nose-mounted vane angle of attack, positive nose up, deg
ALPHA	Model angle of attack, deg
BETA	Model sideslip angle, positive nose left, looking upstream, deg
ROLL	Model roll angle, positive clockwise looking upstream, deg
M_∞	Free-stream Mach number
q_∞	Free-stream dynamic pressure, psf
q_s	Dynamic pressure sensor pressure, psf
p_t	Free-stream total pressure, psfa
p_∞	Free-stream static pressure, psfa

SECTION I
INTRODUCTION

The MGGB system is a high-speed air-launched gliding weapon system. After release, the wings are deployed to provide the desired lifting surfaces. Vehicle attitude and motion requirements are established by an angle-of-attack vane sensor system.

This test was conducted at Mach numbers from 0 60 to 0 95 in order to provide a calibration of the angle-of-attack and dynamic pressure sensor systems and to determine the calibration sensitivity to vehicle design and manufacturing tolerances.

SECTION II
APPARATUS

2.1 TEST FACILITY

Tunnel 16T is a closed-circuit, continuous-flow tunnel capable of operation at Mach numbers from 0.20 to 1.60. The test section is 16 by 16 ft in cross section and is 40 ft long. The tunnel can be operated within a stagnation pressure range from 80 to 4,000 psfa depending on the Mach number. Perforated test section walls allow continuous operation through the Mach number range with a minimum of wall interference. The location of the model in the test section is shown in Fig. 1 (Appendix).

Additional information on the tunnel, its capabilities, and available supporting equipment may be found in the Test Facilities Handbook[1].

2.2 TEST ARTICLE

The model was a full-scale MGGB vehicle with the tail section removed and the wing span shortened in order to reduce the model's aerodynamic loads. The MGGB vehicle is a standard M-82 bomb with a hemispherical nose section containing the guidance equipment, longitudinal strakes, and a strongback section which contains the wing and launch lugs. A photograph of the model installed in the test section is shown in Fig. 2. A dimensional sketch of the model is shown in Fig. 3.

Two vane-type angle-of-attack sensors were mounted on the model. Each vane had a 16-deg included angle wedge-shaped section attached to a shaft which was free to rotate, thereby allowing the vanes to remain aligned with the local airflow around the model. A dimensional sketch and a photograph of the vane are shown in Figs. 4 and 5. One vane was mounted in the normal location beneath and forward of the leading edge of the left wing on the strongback and was part of the strongback winged-section package. The other vane, which was added to obtain a calibration at an alternate location, was mounted on the right side centerline, 18.3 in. aft of the nose.

[1]Test Facilities Handbook (Ninth Edition), "Propulsion Wind Tunnel Facility, Vol. 4." Arnold Engineering Development Center, July 1971.

A dynamic pressure sensor (not normally a component of the MGGB system) was mounted to the lower centerline of the nose section. A dimensional sketch and a photograph of the sensors are shown in Figs. 6 and 7.

Model configuration changes were obtained by placing 1/4- and 1/8-in. spacers between the strongback section and the body section.

2.3 INSTRUMENTATION

To obtain corrections to the model attitude due to aerodynamic loads, four moment strain gages were affixed to the sting. Electrical signals from the moment sting strain gages, pressure transducers, and model angle-of-attack systems were digitized and recorded on magnetic tape as well as fed directly into a computer for on-line data reduction. These on-line data were graphically displayed on a cathode-ray tube and a hard copy plotter.

SECTION III
TEST DESCRIPTION

3.1 PROCEDURE

To obtain data, the tunnel conditions were established, and the model attitude was varied. Model nominal angle of attack was varied from -12 to +12 deg at zero sideslip angle, and sideslip angle was varied from -8 to +8 deg at zero angle of attack. Very limited data were obtained at other combinations of α and β. In order to determine flow angularity corrections, data were obtained with the model upright and inverted.

3.2 PRECISION OF MEASUREMENT

An estimate of the accuracy of the data is presented as follows:

M_∞	ΔM_∞	Δ ALPHA, deg	Δ q_∞, psf	Δ q_s, psf
0.60	±0.0020	±0.10	±1.54	±2.0
0.80	±0.0025	±0.10	±1.06	±2.0
0.90	±0.0030	±0.10	±0.76	±2.0

SECTION IV
RESULTS AND DISCUSSION

4.1 ANGLE-OF-ATTACK VANE SENSOR

Presented in Fig. 8 are calibration data for both of the angle-of-attack vane sensors. In order to determine the local flow angularity. these data were obtained upright and inverted. Generally, the data are linear with the vehicle angle-of-attack range from -11 to +6 deg. Outside this range, the data became nonlinear. Small nonlinearities appear in the data within this range at Mach number 0.85 and greater. The MGGB vane sensor,

located near the lower forward leading edge of the left wing on the strongback, showed a downward angularity of approximately 0.4 deg. This flow angularity is nearly constant with Mach number. The nose-mounted vane sensor, located on the right side of the nose section, indicated a maximum upward flow angularity of approximately 0.1 deg. As shown in Fig. 8, both the calibration slopes and zero-degree intercepts vary with increasing Mach number. Therefore, the manufacturer's static calibration data for the MGGB and nose-mounted vane sensors are not sufficient to properly describe the vehicle attitude.

In order to determine the calibration sensitivity to assembly tolerances, data were obtained with 1/4- and 1/8-in. spacers between the vehicle body and the strongback (wing assembly). Data presented in Fig. 9 show that the spacers affected the flow field in the area of the MGGB vane to such an extent as to cause an increase of about 0.4 deg in the vane angle for a given angle of attack. There is no appreciable difference in the calibration data with the two spacers. The nose-mounted vane sensor generally showed the same effects from the spacers but smaller in magnitude.

The data presented in Fig. 10 show the effect of sideslip angle on the angle-of-attack vane sensor. The MGGB vane sensor is located in a region where the flow field is highly affected by vehicle sideslip. For the nose-mounted vane sensor, there is no appreciable effect of vehicle sideslip angle on the vane angle at small angles of sideslip.

4.2 DYNAMIC PRESSURE SENSOR

The dynamic pressure sensor was an aerodynamically compensated probe. The effects of angle of attack on the sensor pressure is presented in Fig. 11, which shows that, generally, increasing angle of attack decreases sensor dynamic pressure. The discontinuities at Mach numbers 0.85 and 0.90 are apparently the effects of a shock wave generated by the flow accelerating around the vehicle's nose. The data presented in Fig. 12 show that there is no appreciable effect on the sensor dynamic pressure due to the vehicle's sideslip angle. Additional calibration data are presented as functions of Mach number in Figs. 13 and 14. These data show that the sensor pressures must be decreased by approximately 25 percent in order to agree with the free-stream dynamic pressures at Mach numbers from 0.60 to 0.80.

SECTION V
CONCLUSIONS

The results of the test conducted on two vane-type angle-of-attack sensors and a dynamic pressure sensor produced the following conclusions:

1. The flow field, in the region of the MGGB vane-type angle-of-attack sensor located ahead of the inboard leading edge of the left wing, is greatly influenced by vehicle attitude.

2. The static calibration furnished by the vane manufacturer is not sufficient to properly describe the vehicle attitude. For both vanes, the calibration slopes can be readily adjusted. For the nose-mounted vane, the reading at

an angle of attack of zero can be adjusted. However, because of the complexity of the flow field in the region of the MGGB vane, the zero degree angle of attack reading was not constant with increasing Mach number. A mean value could be used that would yield reasonable results.

3. If the MGGB vane angle-of-attack sensor is to be used to describe vehicle angle of attack, sideslip angles must be avoided.

4. If the dynamic pressure sensor is to be used to obtain free-stream dynamic pressure, the sensor reading must be decreased by about 25 percent. This would give accurate data at free-stream Mach numbers from 0.60 to 0.80.

APPENDIX
ILLUSTRATIONS

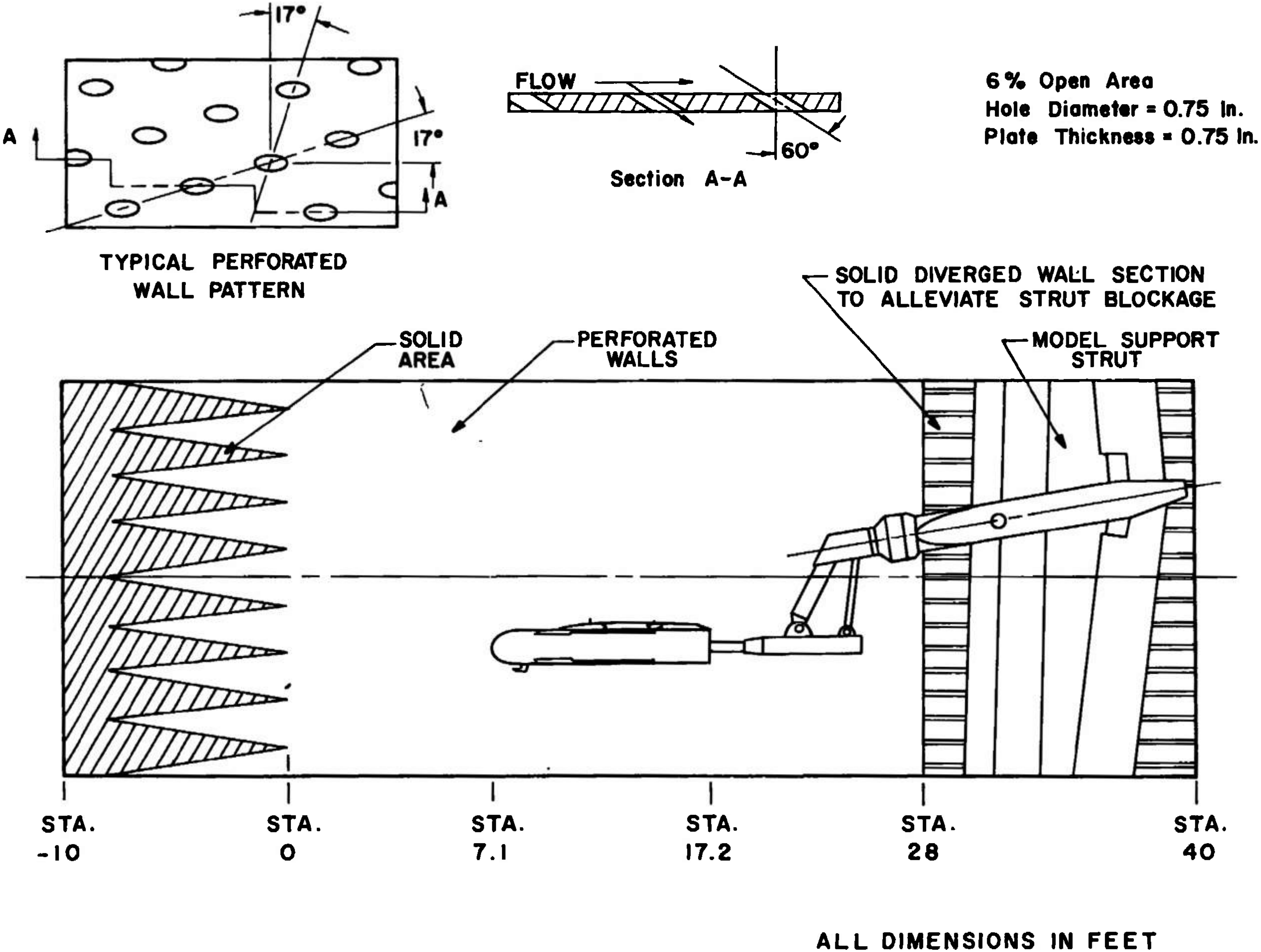


Fig. 1 Sketch of Model in Test Section

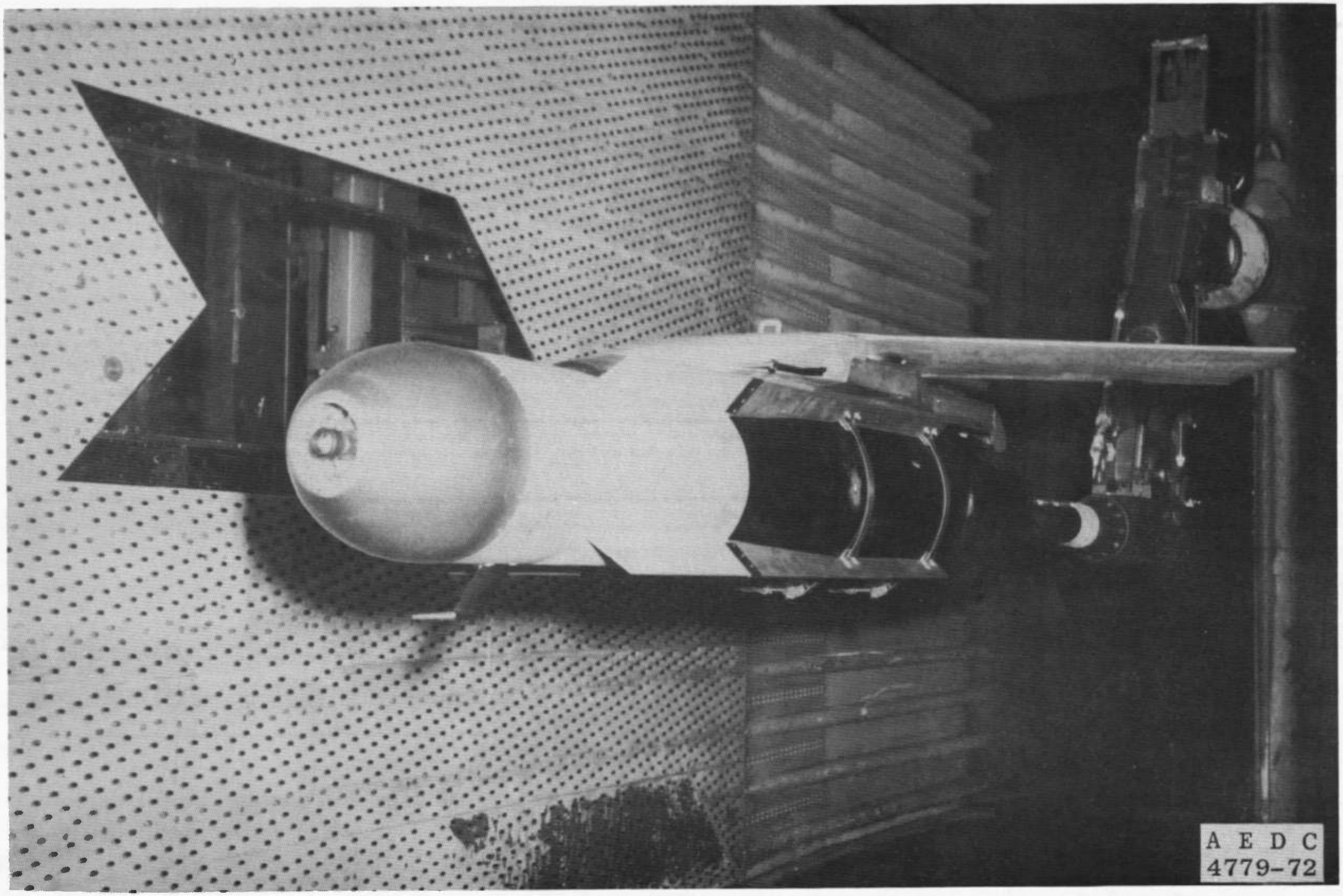


Fig. 2 Photograph of Model Installed in Test Section

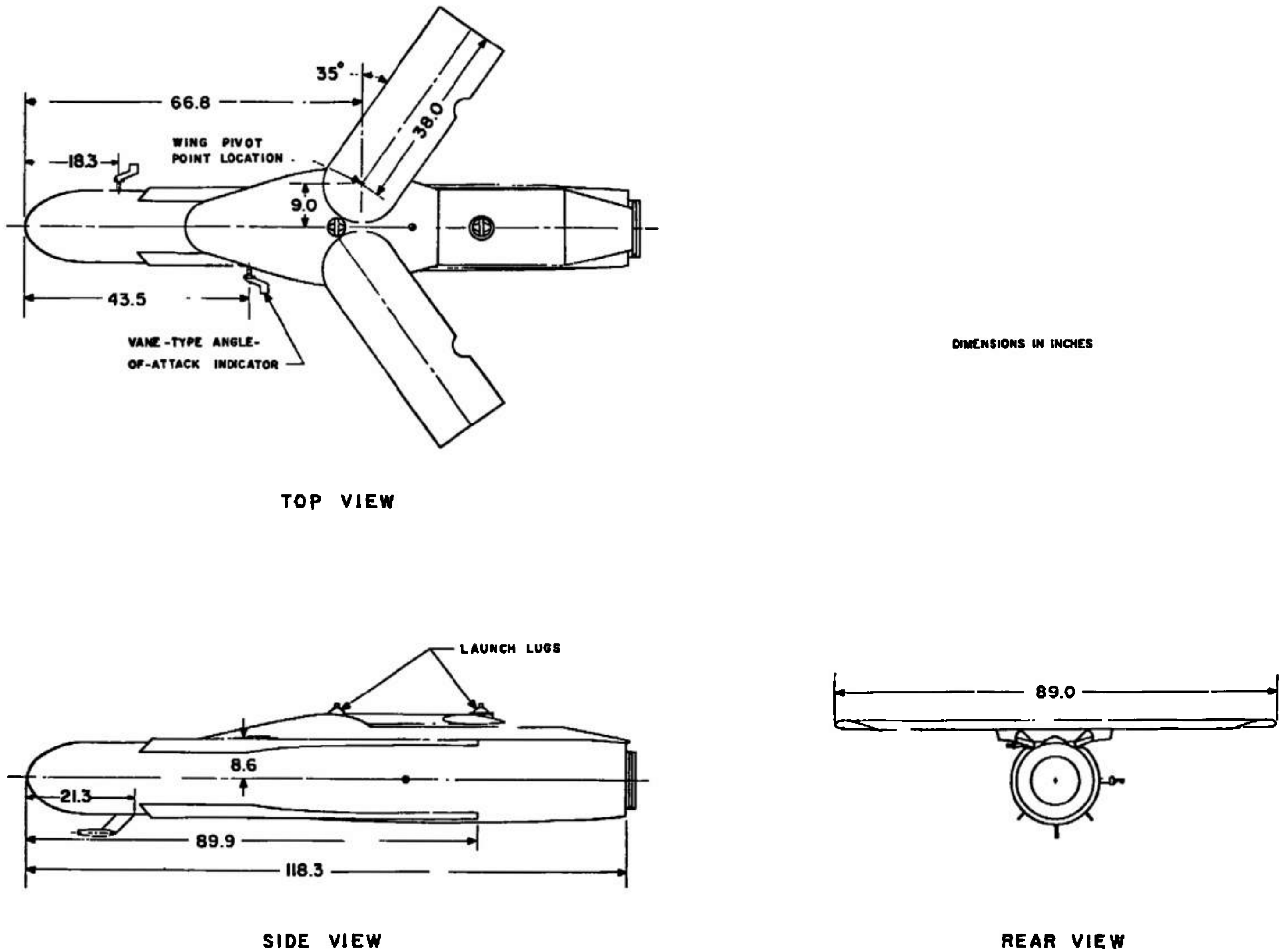


Fig. 3 Dimensional Sketch of the Model

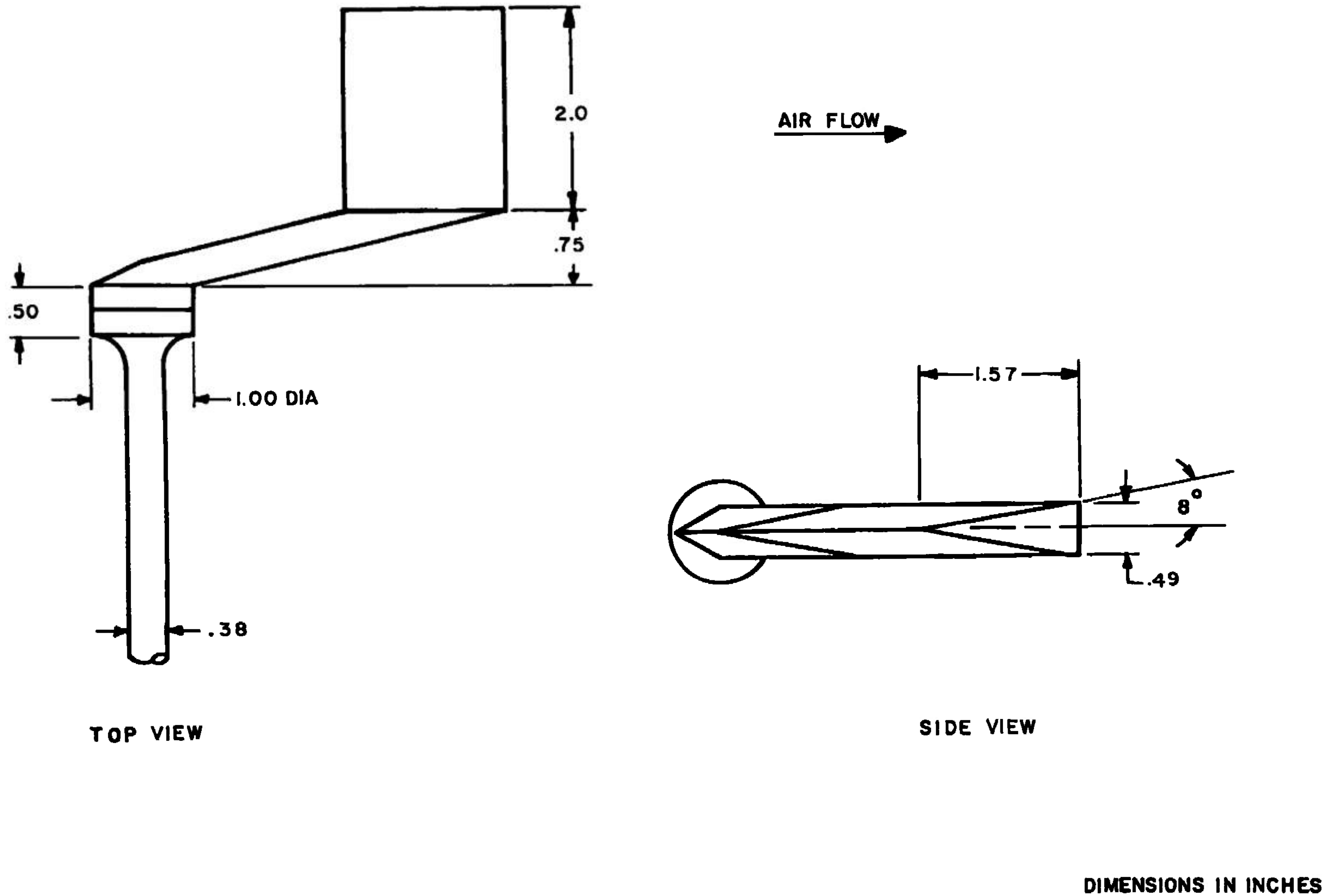


Fig. 4 Details of Angle-of-Attack Vane

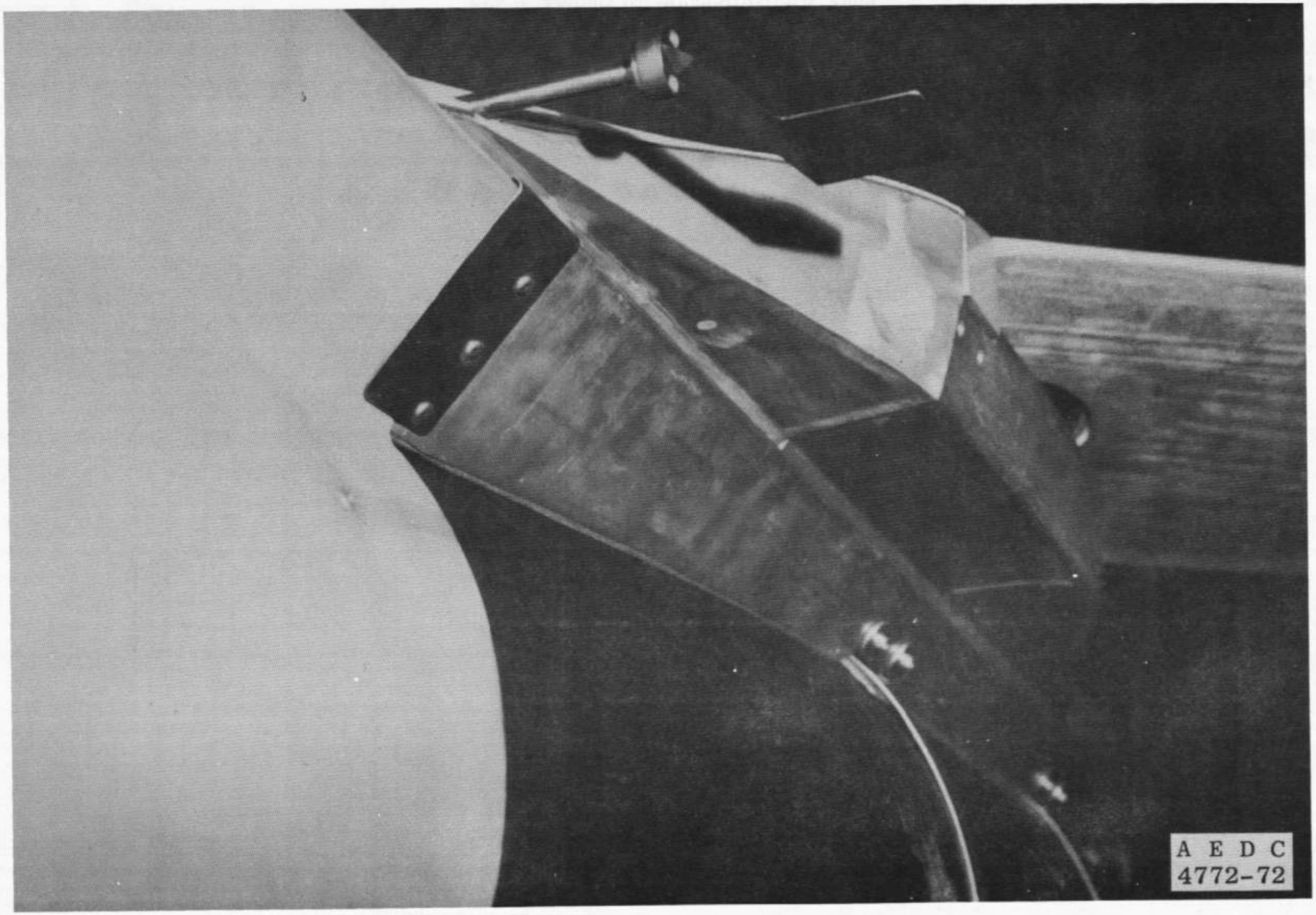
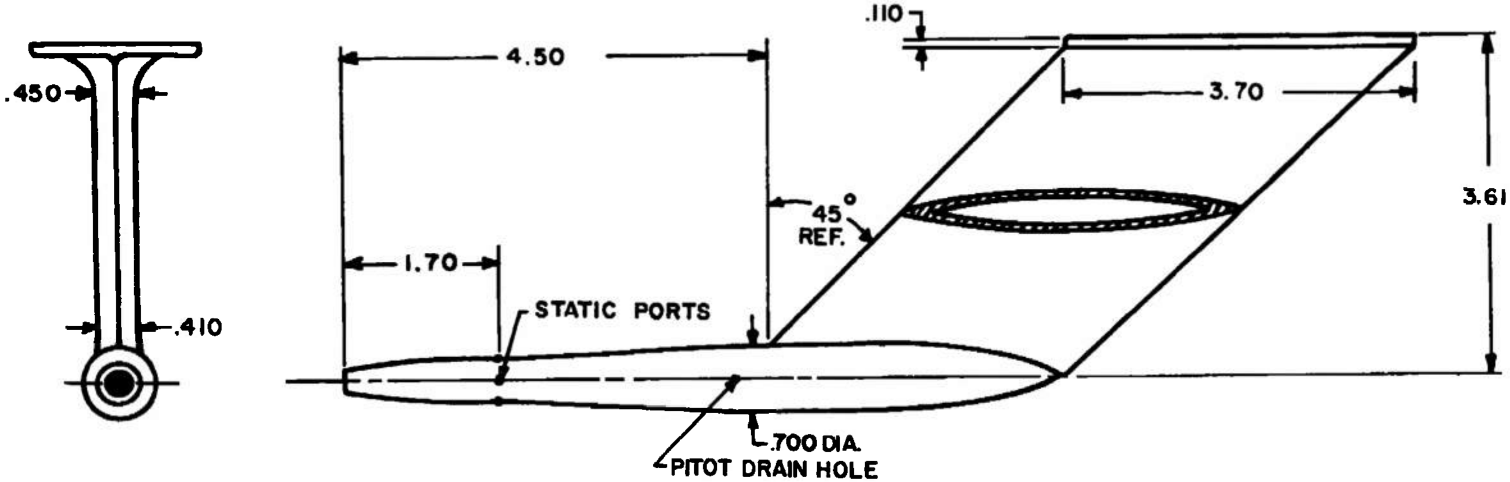


Fig. 5 Photographs of MGGB Angle-of-Attack Vane



DIMENSIONS IN INCHES

Fig. 6 Details of Dynamic Pressure Sensor

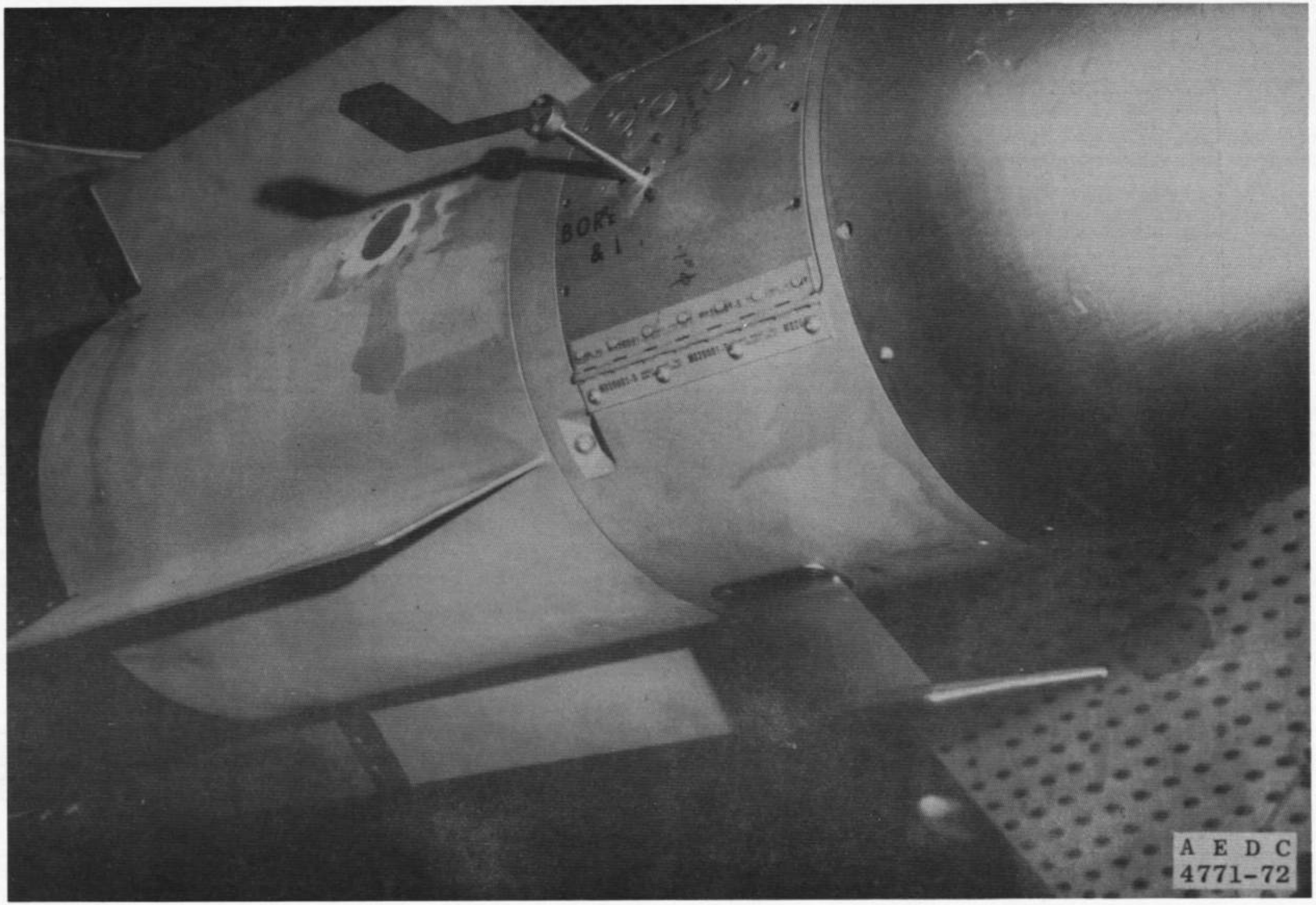


Fig. 7 Photograph of Dynamic Pressure Sensor and the Nose-Mounted Angle-of-Attack Vane

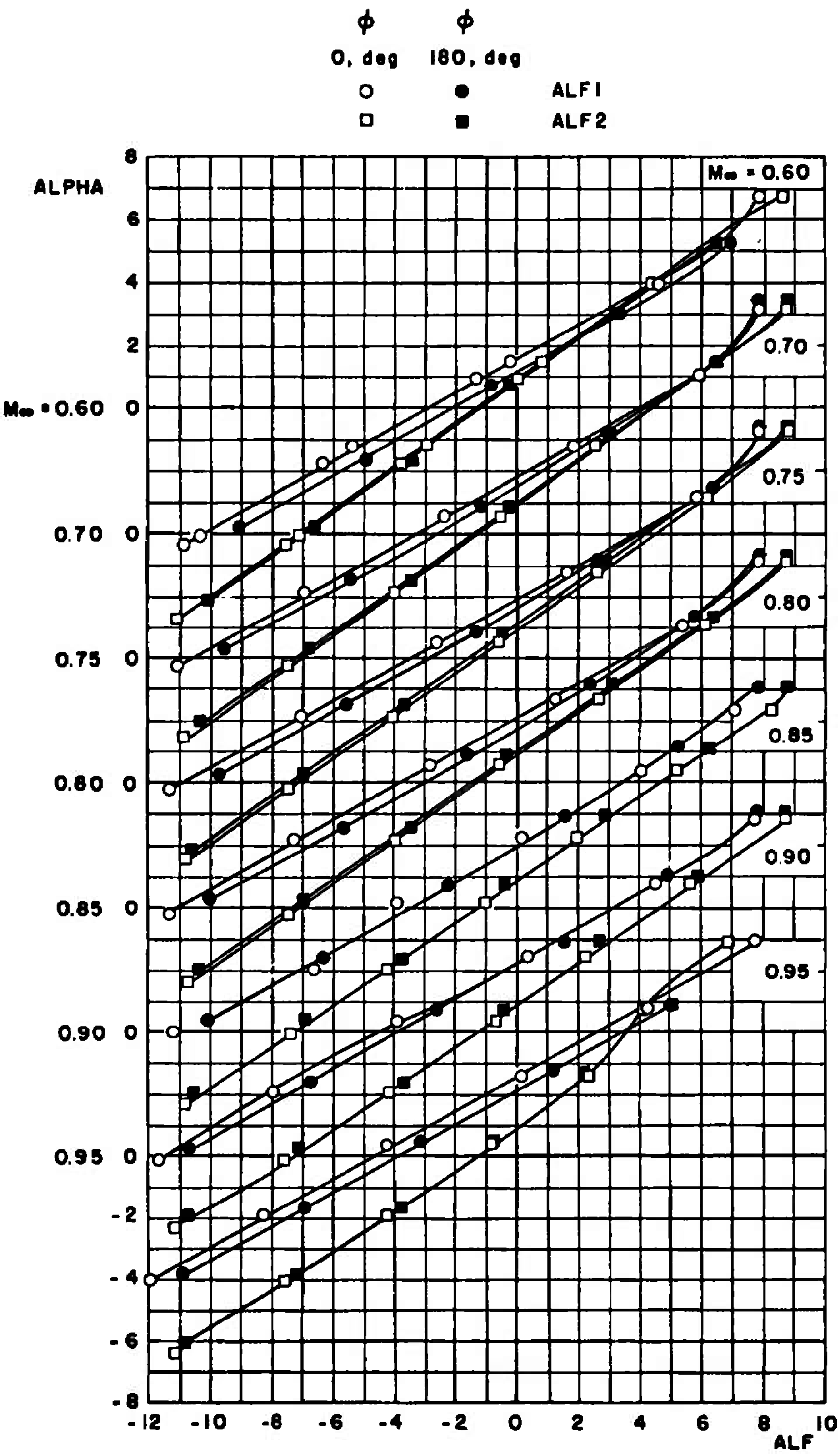
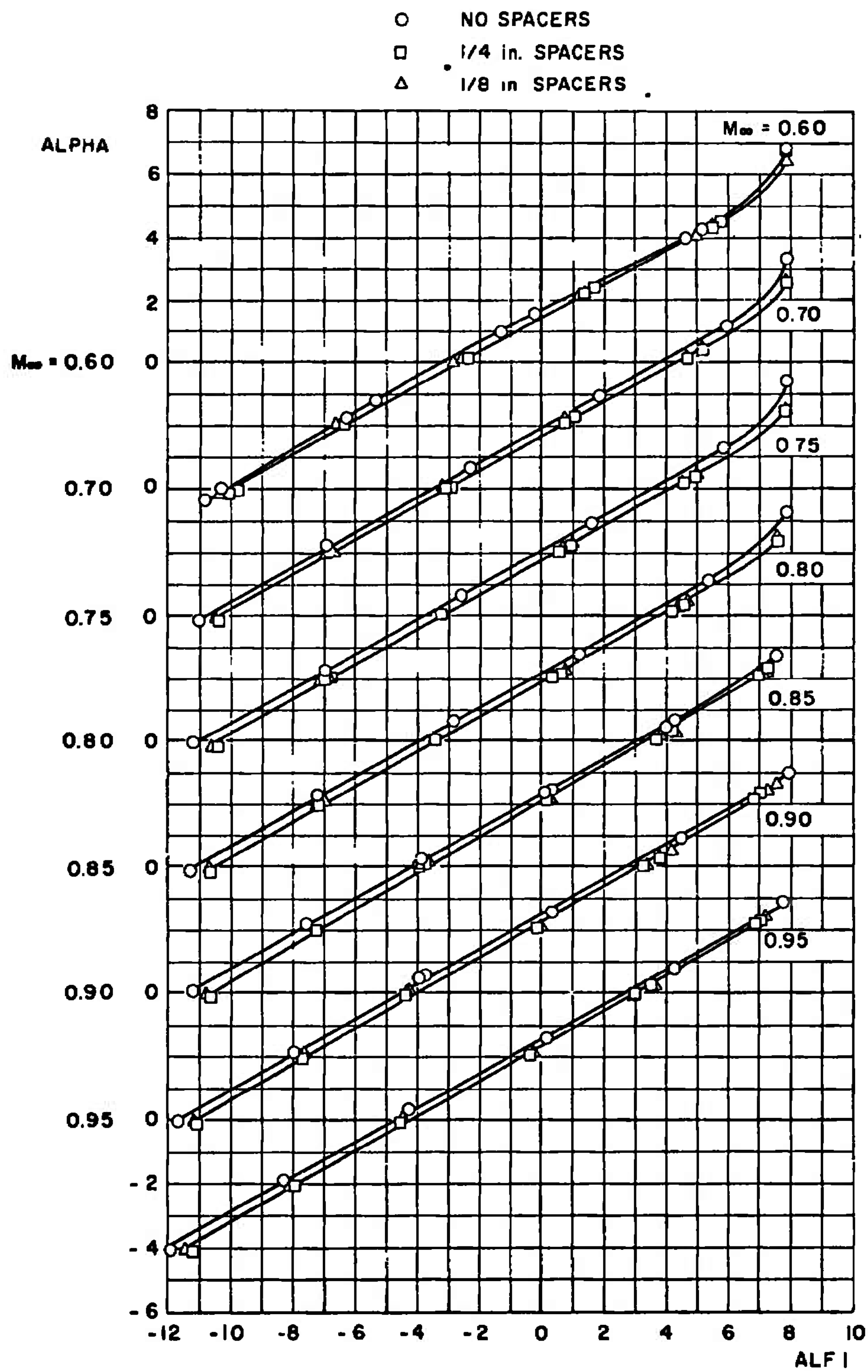
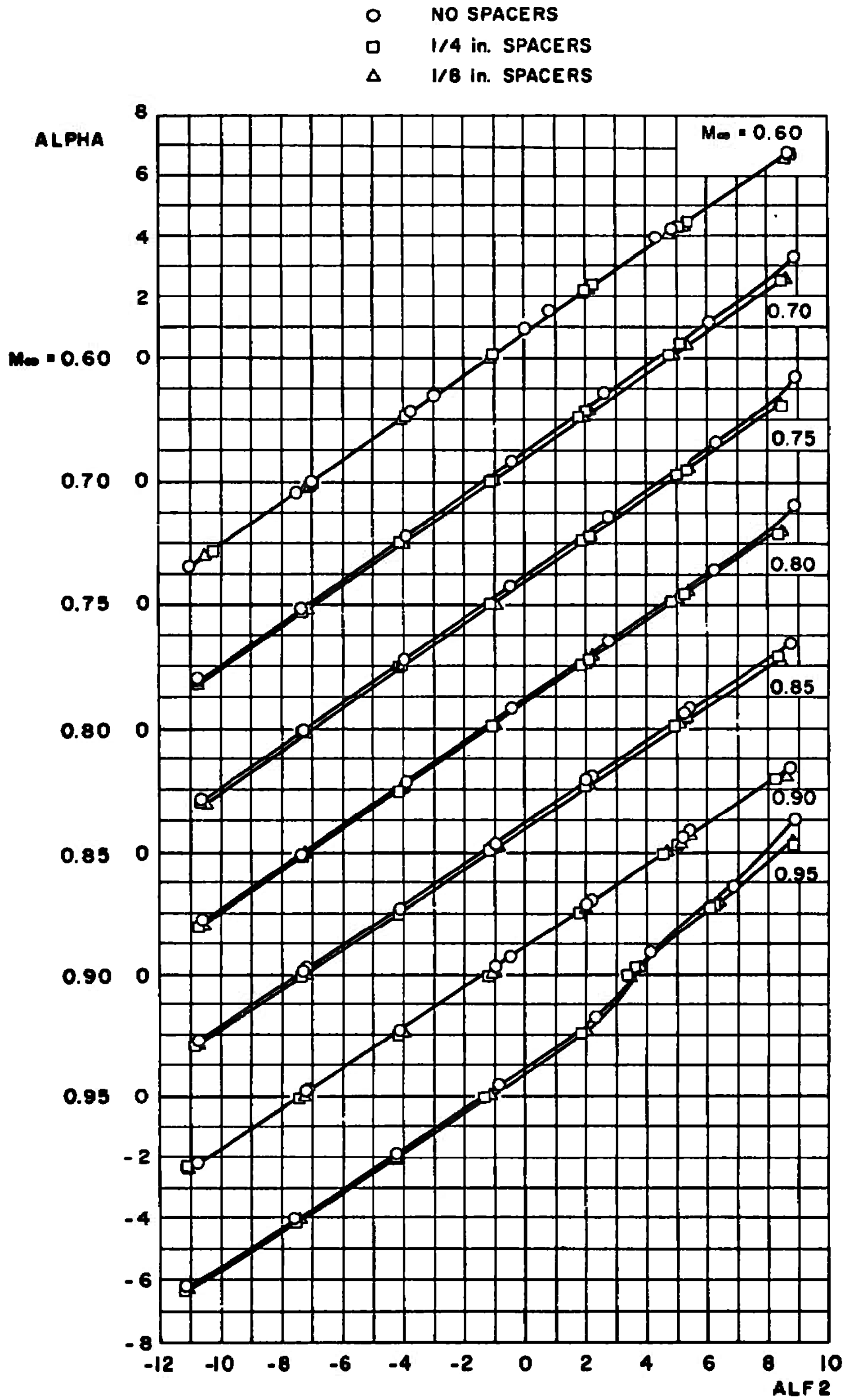


Fig. 8 Variation of the Vane Sensor Angle of Attack with Model Angle of Attack

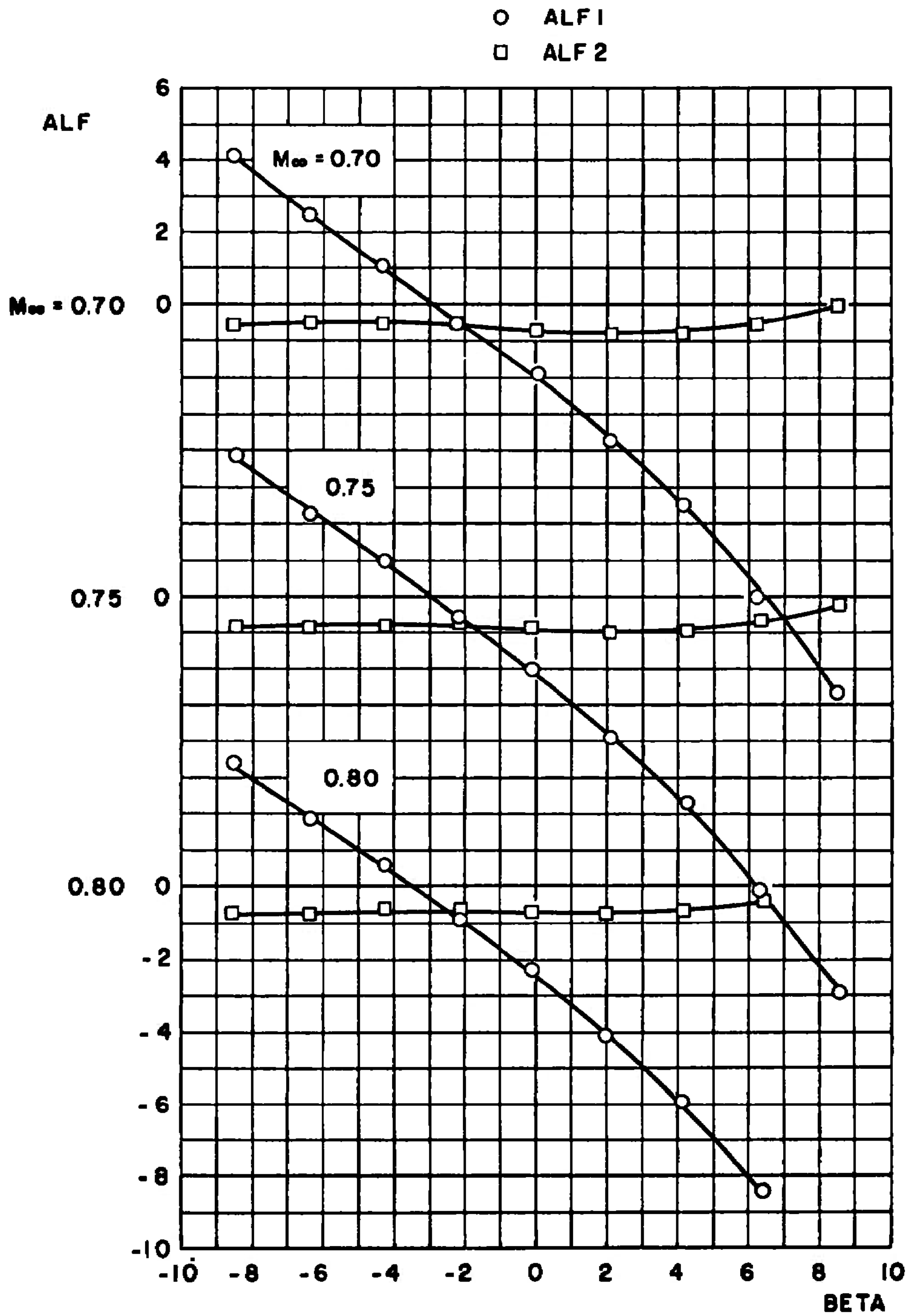


a. MGGB Vane

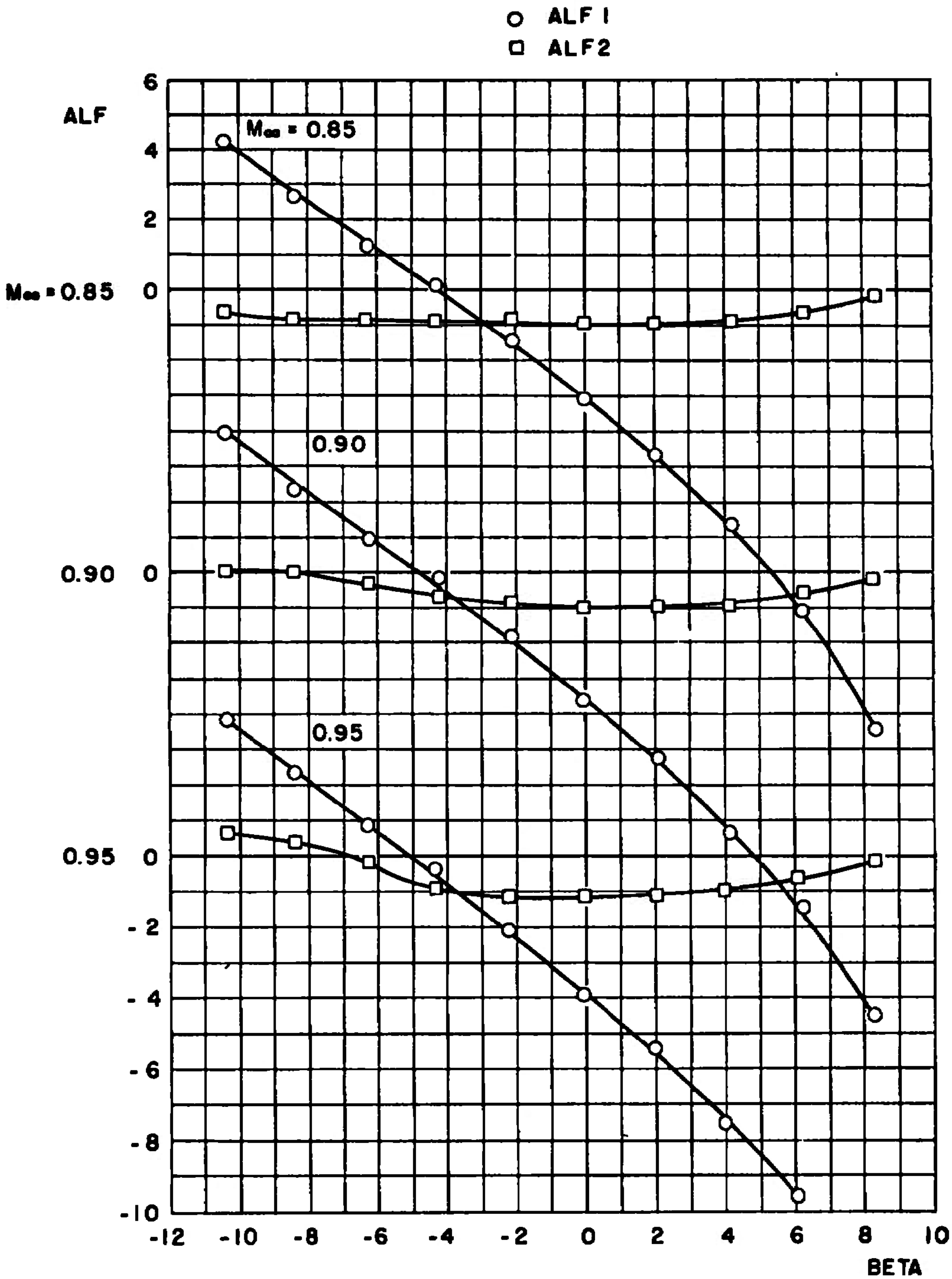
Fig. 9 Effects of Wing-to-Body Spacers on Vane Sensor Angle of Attack



b. Nose Mounted Vane
Fig. 9 Concluded



a. M_∞ = 0.70 to 0.80
Fig. 10 Effects of Sideslip Angle on Vane Sensor Angle of Attack



b. M_∞ = 0.85 to 0.95
Fig. 10 Concluded

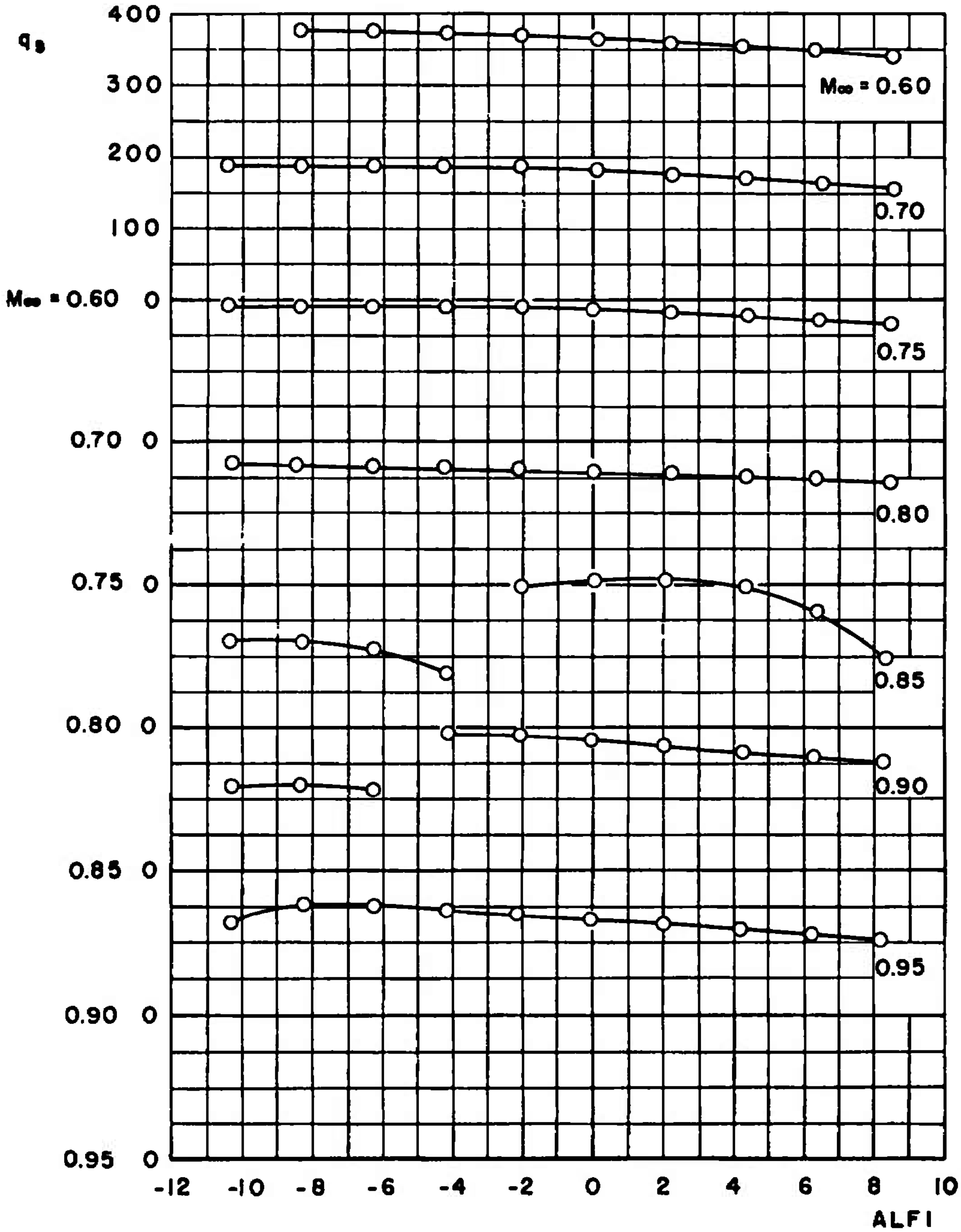


Fig. 11 Effects of Angle of Attack on Dynamic Pressure Sensor

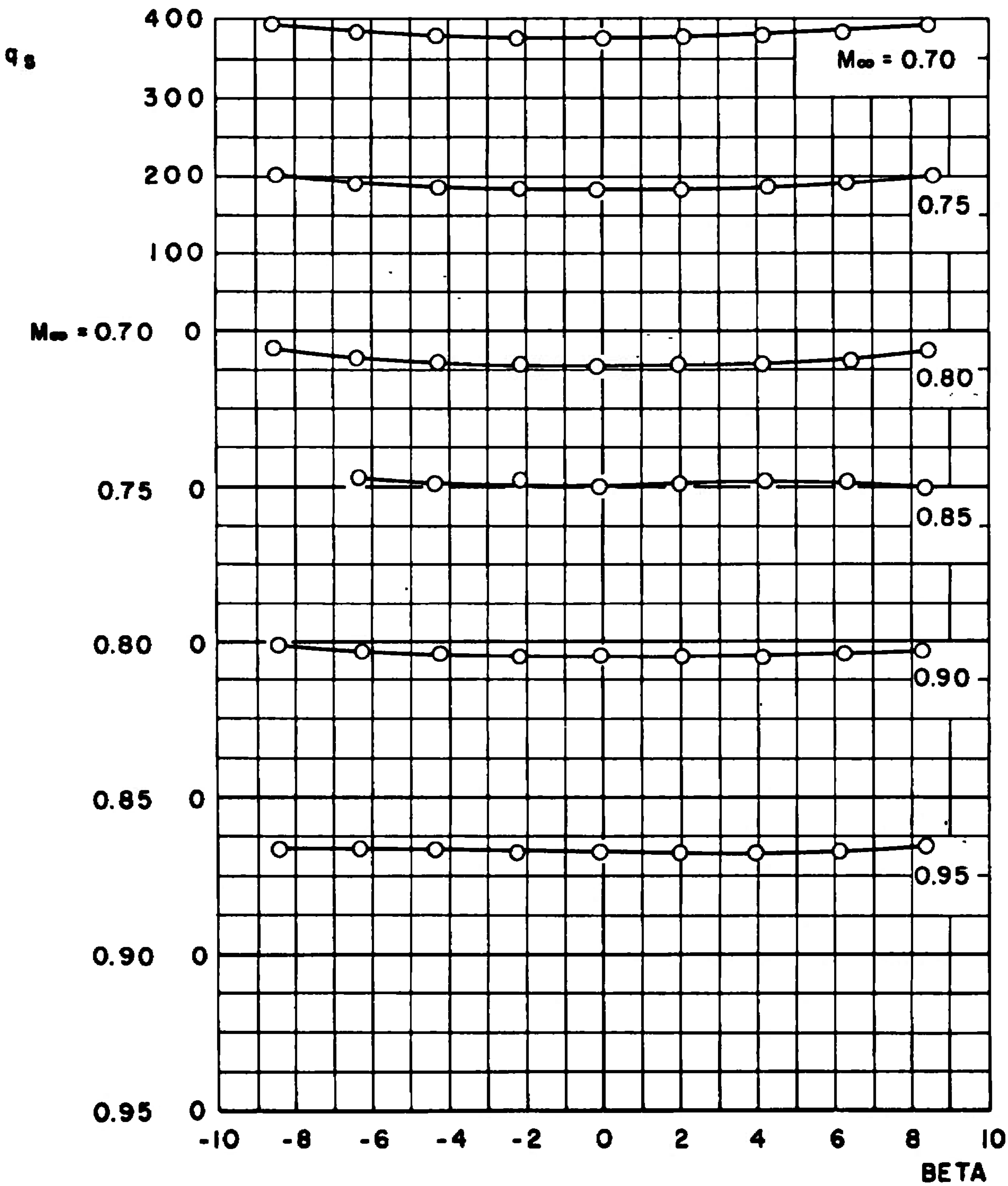


Fig. 12 Effects of Sideslip Angle on Dynamic Pressure Sensor

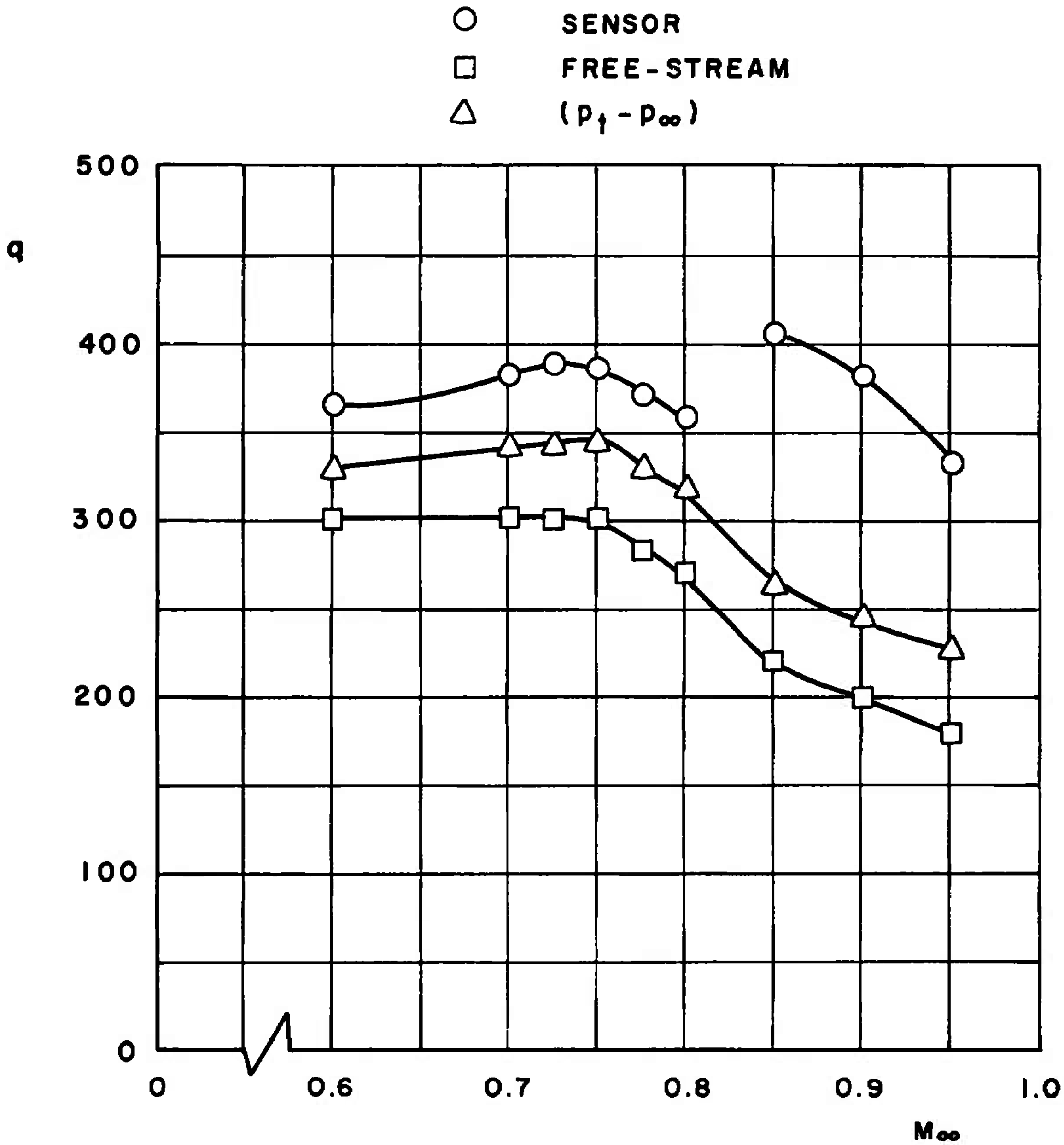


Fig. 13 Variation of Dynamic Pressure with Mach Number

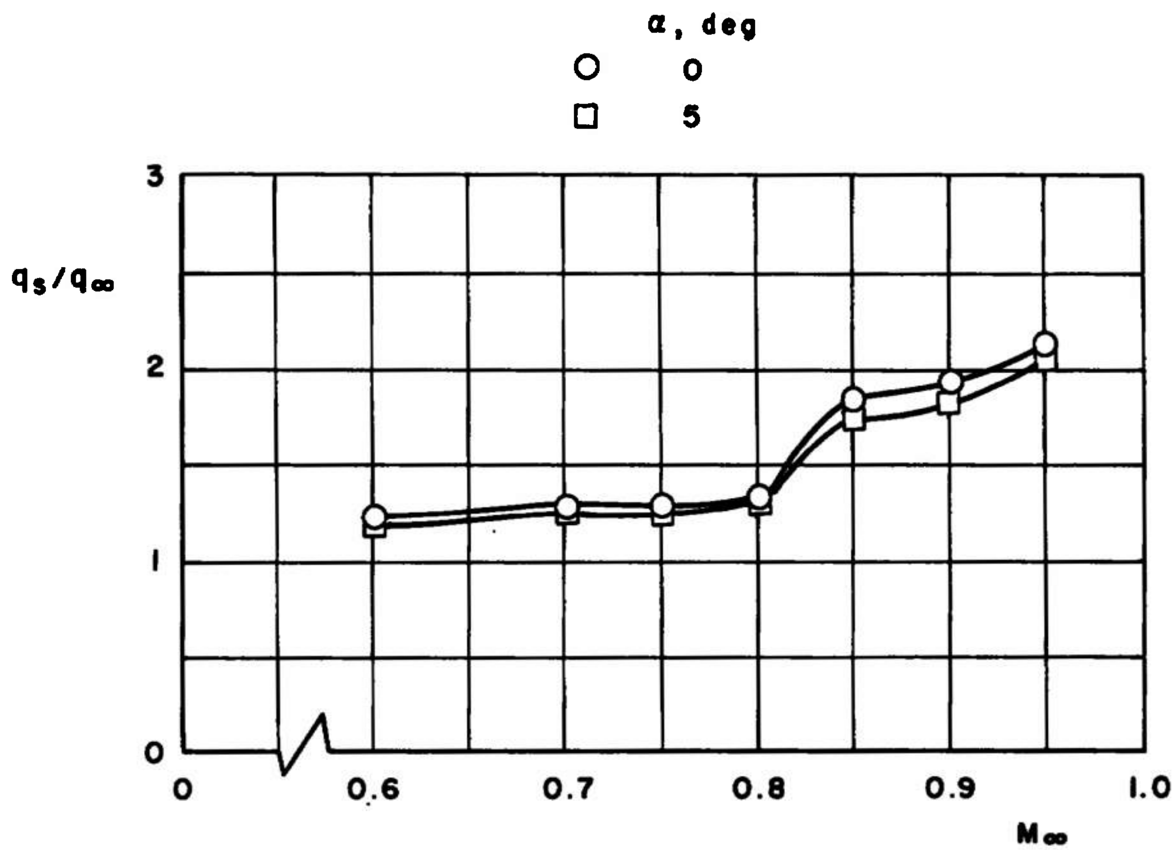


Fig. 14 Variation of Sensor Dynamic Pressure Ratio with Mach Number

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13. ABSTRACT

A wind tunnel test was conducted at Mach numbers from 0.60 to 0.90 in the Propulsion Wind Tunnel Transonic (16T) to provide a calibration of angle-of-attack and dynamic pressure sensors mounted on a full-scale Modular-Guided Glide Bomb (MGGB) with the glide bomb tail section removed and the wing span shortened. The data indicate that in addition to the data supplied by the manufacturer of the angle-of-attack vanes, calibration data are necessary to properly define the attitude of the vehicle. The dynamic pressure sensor readings must be reduced by approximately 25 percent to yield accurate free-stream data at Mach numbers from 0.60 to 0.80.

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